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PATENT
0925-0154P

IN THE U.S. PATENT AND TRADEMARK OFFICE

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09/887665
01/12/00

Applicant:	Koji MINAMI, et al.	Conf.:	5581
Appl. No.:	09/~~481,391~~ 887,665	Group:	2614
Filed:	January 12, 2000	Examiner:	B. Yenke
For:	DISPLAY DEVICE		

LARGE ENTITY TRANSMITTAL FORM

Assistant Commissioner for Patents
Washington, DC 20231

May 22, 2001

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Sir:

Transmitted herewith is an amendment in the above-identified application.

☐ The enclosed document is being transmitted via the Certificate of Mailing provisions of 37 C.F.R. § 1.8.

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The fee has been calculated as shown below:

	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR		PRESENT EXTRA	RATE	ADDITIONAL FEE
TOTAL	7	-	20	=	0	$18	$0.00
INDEPENDENT	2	-	3	=	0	$80	$0.00
☐ FIRST PRESENTATION OF A MULTIPLE DEPENDENT CLAIM						$270	$0.00
						TOTAL	$0.00

☒ Petition for three (3) month(s) extension of time pursuant to 37 C.F.R. §§ 1.17 and 1.136(a). $890.00 for the extension of time.

☐ No fee is required.

☒ A check in the amount of $890.00 is enclosed.

☐ Please charge Deposit Account No. 02-2448 in the amount of $0.00. This form is submitted in triplicate.

If necessary, the Commissioner is hereby authorized in this, concurrent, and future replies, to charge payment or credit any overpayment to Deposit Account No. 02-2448 for any additional fees required under 37 C.F.R. § 1.16 or under 37 C.F.R. § 1.17; particularly, extension of time fees.

Respectfully submitted,

BIRCH, STEWART, KOLASCH & BIRCH, LLP

By ____________________
John A. Castellano, #35,094

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JAC:cb
0925-0154P

ATTACHMENT

(Rev. 01/22/01)

#7

PATENT
0925-0154P

IN THE U.S. PATENT AND TRADEMARK OFFICE

Applicant:	Koji MINAMI, et al.	Conf. No.:	5581
Application No.:	09/~~481,39~~1 957,665	Group:	2614
Filed:	January 12, 2000	Examiner:	B. Yenke
For:	DISPLAY DEVICE		

AMENDMENT

Assistant Commissioner for Patents
Washington, DC 20231

May 22, 2001

Sir:

In reply to the Examiner's Office Action dated November 22, 2000, the period for response having been extended three (3) months to May 22, 2001, the following amendments and remarks are respectfully submitted in connection with the above-identified application.

IN THE SPECIFICATION:

Please replace the specification filed on January 12, 2000 with the specification attached hereto.

IN THE CLAIMS

Please cancel claims 1-~~10~~ 1-3 and add the following new claims ~~11-17~~ 4-.

--~~11~~ 4. A display device for displaying an image according to input image data that is digital data, said display device comprising:

a light source for producing light;

light-transmitting filters for separating the light from said light source into at least four kinds of light including white light, said light-transmitting filters including a white-transmitting filter for transmitting white light and non-white transmitting filters;

a light valve for projecting each kind of light from said light-transmitting filters onto a screen;

said white light-transmitting filter being used to display information corresponding to lower-order bits of said digital data;

said non-white light-transmitting filters being used to display information corresponding to higher-order bits of said digital data.

5 ~~12~~. The display device of claim 11, wherein said white light-transmitting filter has spectral characteristics that are almost flat in the visible range of wavelengths of the light.

6 ~~13~~. The display device of claim 11, wherein if a brightness required by the input image data is lower than a given gray level, information is displayed using said white light-transmitting filter or said non-white light-transmitting filters, and if said brightness is higher than said given gray level, information is displayed using only said non-white light-transmitting filters.

7
~~14~~. The display device of claim 11, wherein said light valve is of the reflective type.

8
~~15~~. The display device of claim 11, wherein said light valve is of the transmissive type.

9
~~16~~. The display device of claim 11, wherein a value obtained by integrating the product of spectral transmission factor of said white light-transmitting filter in the visible range and spectral luminous efficiency with respect to wavelength is less than sum of values obtained by integrating the product of spectral transmission factor of each of said non-white light-transmitting filters in the visible range and spectral luminous efficiency with respect to wavelength.

10
~~17~~. The display device of claim 11, wherein brightness created by a first gray level represented via said white light-transmitting filter is lower than brightness created by a first gray level represented via said non-white light-transmitting filters.--

REMARKS

Claims 11-17 are pending in the present application. Reconsideration of the present application, is respectfully requested.

Rejections

The Examiner has provisionally rejected claims 1-10 under 35 U.S.C. §102(e) as being anticipated by co-pending application no. 09/369,310, has provisionally rejected claims 1-10 under 35 U.S.C. §101 as claiming the same invention as that of claims 1-10 of co-pending application no. 09/369,310, and has raised 102(g) and/or 102(f) issues with regard to claims 1-10 of co-pending application no. 09/369,310.

Applicants respectfully submit that a Petition Under 37 C.F.R. §1.182 was filed in the present application on April 9, 2001 in order to consider Japanese Priority application 079518/1999 as the specification in the present application and not the English-language specification which was attached during filing on January 12, 2000. Applicants direct the Examiner's attention to the Petition filed in the present application on April 9, 2001. Applicants respectfully submit that the amendments to replace the English-language specification filed on January 12, 2000 with an English-language translation of the Japanese priority document, the replacement of the Figures, and the cancellation of claims 1-10 and the replacement with claims 11-17 render moot

all of the rejections contained in the Examiner's Office Action of November 22, 2000. Applicants further request the Examiner to refrain from further action on the present application until applicant's Petition filed April 9, 2001 is decided upon.

CONCLUSION

In the event there are any outstanding matters remaining in this application, the Examiner is invited to contact John A. Castellano (Reg. No. 35,094) at (703) 205-8000 in the Washington, D.C. area.

Pursuant to 37 C.F.R. §§ 1.17 and 1.136(a), Applicants respectfully petition for a three (3) month extension of time for filing a reply in connection with the present application, and the required fee of $890.00 is attached hereto.

If necessary, the Commissioner is hereby authorized in this, concurrent, and future replies, to charge payment or credit any overpayment to Deposit Account No. 02-2448 for any additional fees required under 37 C.F.R. § 1.16 or under 37 C.F.R. § 1.17; particularly, extension of time fees.

Respectfully submitted,

BIRCH, STEWART, KOLASCH & BIRCH,LLP

By ______________________________

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JAC:cb
0925-0154P

Application No. 09/481,391
Attorney Docket No.: 0925-0154P

MARKED-UP VERSION

In the Specification

The entire specification has been replaced

In the Claims

Claims 1-10 have been canceled
Claims 11-17 have been added

[Name of Document]: Specification

[Title of the Invention]: Display Device

[Claims]

1. In a display device having a light source and four or more kinds of color filters including a color filter Cw showing almost flat transmission spectral characteristics in the visible range, the display device being designed to display an image by passing light emitted from said light source through the color filters,

the improvement wherein information corresponding lower-order m bits of a brightness signal of a color image signal quantized with $(n + m)$ bits (where n and m are real numbers equal to or greater than 0) is displayed only with the light passed through said color filter Cw, and wherein information corresponding to upper-order n bits is displayed by light passed through the color filters other than said color filter Cw.

2. In a display device having a light source and four or more kinds of color filters including a color filter Cw that transmits white light, the display device being designed to display an image by passing light emitted from said light source through the color filters,

the improvement wherein information corresponding lower-order m bits of a brightness signal of a color image signal quantized with $(n + m)$ bits (where n and m are real numbers equal to or greater than 0) is displayed only with the light passed

through said color filter Cw, and wherein information corresponding to upper-order *n* bits is displayed by light passed through the color filters other than said color filter Cw.

3. In the display device set forth in claim 1 or 2, the further improvement wherein a display is provided using light transmitted through the color filter Cw only when a signal corresponding to brightness information of said color image signal is less than a given gray level.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Belongs]

The present invention relates to a display device and, more particularly, to a display device using color filters to reproduce colors.

[0002]

[Prior Art Techniques]

In recent years, numerous display devices have been available in which color filters are used to decompose light from a light source into N kinds of colors that are projected onto a screen for reproducing a color image, where N is a positive integer. Normally, N = 3, and light is decomposed into red (R), green (G), and blue (B) colors which are projected to reproduce a color image.

[0003]

Fig. 5 is a diagram showing a first conventional example

of a display device.

[0004]

Shown in Fig. 5 are a light source 101, a color wheel 102, a light valve 103, a screen 104, and a driver portion 105. The display device shown in Fig. 5 is assumed to project light decomposed into R, G, and B colors, thus reproducing color images.

[0005]

The operation of the first conventional display device is described below by referring to Fig. 5. Seven-bit color image data having a frame rate of 60 Hz and a synchronizing signal are applied to the driver portion 105. The driver portion 105 creates control signals for the color wheel 102 and for the light valve 103 from the entered color image data and the synchronizing signal. The control signals are fed to the color wheel 102 and to the light valve 103.

The light valve 103 is a device for turning ON or OFF light for each individual pixel. A digital micromirror device (hereinafter abbreviated DMD), a liquid crystal, or the like is used as the light valve 103. Where the DMD is used as the light valve 103, the direction in which light is reflected is controlled for each individual pixel, thus turning ON or OFF the light. Where the light is reflected toward the screen, the device is turned ON. Where the light is reflected toward the outside the screen, the device is turned OFF. This will

hereinafter be referred to as "control of the reflection". In the case of a liquid crystal, two types are conceivable. One type controls reflection in the same way as the aforementioned DMD. Another type switches ON and OFF passage of light for each individual pixel. Where the light is transmitted, the device is turned ON. Where the light is not transmitted, the device is turned OFF. It is now assumed that the transmitted light is brought to a focus on the screen.

[0006]

An ultrahigh-pressure mercury lamp is used as the light source 101, for example. Light emitted from this lamp is made to hit a part of the color wheel 102.

[0007]

The color wheel 102 is divided into three segments, for example. These segments are color filters Cr, Cg, and Cb that transmit R, G, and B, respectively. The color wheel 102 makes one revolution in 1/60 msec, i.e., about 16.667 msec. This rotation is synchronized to the frame rate of the displayed image.

[0008]

Where light from the light source 101 shines on the color filter segment Cr on the color wheel 102, the light valve 103 is controlled by color image data about R. An R image is projected onto the screen 104. With respect to other colors, the light from the light source 101 is similarly projected onto the screen

104 via the color filters on the color wheel 102 and via the light valve 103, and images are displayed.

[0009]

The times for which the light from the light source 101 is made to shine on the segments of the color wheel 102 during one revolution of the color wheel 102 are next described. The light source 101 illuminates parts of the color wheel 102. At this time, the light spot has some diameter. Where this light spot is at the boundary between two adjacent color filters, two colors across the boundary will be mixed up. This cannot be used for image display. Therefore, it is necessary to turn OFF the light valve. For the sake of illustration, it is assumed that the light valve must be kept OFF within an angular range of 15° on the color wheel 102. Of course, this angular range may differ, depending on the size of the light spot and on the sizes of the color filters.

[0010]

Since the boundaries between the color filters on the color wheel 102 are three, it is necessary to turn OFF the light valve 103 for a time corresponding to an angular range of $15 \times 3 = 45°$ during one revolution of the color wheel 102. This time is referred to as the ineffective time. The other time is referred to as the effective time. Since the color wheel 102 makes one revolution in about 16.667 msec, the ineffective time is $45°/360° \times 16.667 \cong$ approximately 2.083 msec.

Of the effective time, the time for which the light shines on the color filter Cr is equal to the effective time divided by 3, i.e., about 4.862 msec. Similarly, the time for which the light shines on the color filters Cg and Cb is about 4.862 msec.

[0011]

A method of reproducing gray levels regarding R is now described.

[0012]

When the light shines on the color filter Cr during the effective time of the color wheel 102, the light valve 103 is controlled according to an R image signal. Where the first gray level of R image signal is displayed, the light valve 103 is turned ON for about 0.038 msec within the time for which the light shines on the color filter Cr during one revolution of the color wheel 102. The light valve 103 is kept OFF during the remaining time of about 4.824 msec. Where the second gray level is displayed, the light valve 103 is turned ON for twice of the ON time for the first gray level, i.e., 0.076 msec. The light valve is kept OFF during the remaining time of 4.786 msec. Where the third, fourth, …, and 127th gray levels are displayed, the light valve is turned ON for 3 times, 4 times, …, and 127 times, respectively, the ON time for the first gray level. The light valve is kept OFF during the remaining times. Thus, there are 128 combinations of ON/OFF times including a fully OFF state.

[0013]

The human eye does not respond to flickers higher than 60 Hz, which is generally known as the critical fusion frequency. As the ON time increases within the 16.667 msec, the human eye feels brighter. As the ON time shortens, the eye feels darker. The human eye perceives 128 ON/OFF time combinations as 128 gray levels.

[0014]

Light is projected onto the screen such that the light valve is turned ON or OFF for each pixel, and an R image that visually has gray levels is reproduced.

[0015]

With respect to each of G and B, 128 gray levels are reproduced in exactly the same way.

[0016]

Each image of R, G, and B is projected in turn onto the screen for one third of 1 frame time of about 16.667 msec, i.e., about 5.556 msec. As mentioned above, the human eye does not respond to flickers higher than the critical fusion frequency of 60 Hz and so he or she feels as if three colors were displayed simultaneously. Consequently, a color image is visually reproduced.

[0017]

In the first conventional example described thus far, gray levels corresponding to 7 bits, i.e., 128 gray levels are represented. The light valve 103 is switched ON and OFF at

intervals of about 0.038 msec, i.e., the time (about 4.862 msec) for which light is made to shine on the color filter Cr divided by 127. Where it is attempted to display 256 gray levels corresponding to 8 bits in this first conventional example, it is necessary to switch ON and OFF the light valve 103 at intervals within the time for which light is made to shine on the color filter Cr divided by 255, i.e., about 0.019 msec. If it is assumed that the minimum switching time in which the light valve 103 turns ON and OFF light is about 0.030 msec, then it is impossible to achieve.

[0018]

A second conventional example capable of displaying 1024 gray levels if the minimum switching time in which the light valve 103 turns ON and OFF light is about 0.030 msec is now given. The second conventional example is a technique disclosed, for example, in Japanese Unexamined Patent Publication No. 149350/1997.

[0019]

Fig. 6 is a diagram showing the second conventional example. Those portions which have the same functions as their counterparts in Fig. 5 are indicated by the same numerals in both figures and thus will not be described below.

[0020]

In this second conventional example, a color wheel 202 is divided into 6 segments to add color filters Crd, Cgd, and

Cbd of lower transmissivity compared with the first conventional example. These are used to add gray levels corresponding to the 3 bits.

[0021]

The second conventional example is described below by referring to Fig. 6. In the figure,

[0022]

a driver portion 205 receives 10-bit color image data having a frame rate of 60 Hz and a synchronizing signal. The driver portion 205 creates control signals for a color wheel 202 and for a light valve 103 from the input color image data and sends these control signals to the wheel 202 and to the light valve 103.

[0023]

Of the 6 segments on the color wheel 202, the color filters Cr and Crd transmit R. The color filters Cg and Cgd transmit G. The color filters Cb and Cbd transmit B. The transmissivity of the filter Crd is one eighth of that of the filter Cr. The transmissivity of the color filter Cgd is one eighth of that of the filter Cg. The transmissivity of the color filter Cbd is one eighth of that of the filter Cb. The color wheel 202 makes one revolution in 1/60 msec ≅ 16.667 msec. This rotation is synchronized to the frame rate of the displayed image.

[0024]

In the second conventional example, there are 6 kinds of

color filters and so there exist 6 boundaries. Therefore, the ineffective time is about $15° \times 6 / 360° \times 16.667$ msec $\cong 4.167$ msec. The effective time is about 16.667 msec − 4.167 msec = 12.500 msec.

[0025]

The time for which the light from the light source 101 is made to shine on the color filter Cr of the color wheel 202 during one revolution of the color wheel 202 is about 12.500 msec / 3 × 127 / (127 + 7) = 3.949 msec. Similarly, the time for which light is made to hit the color filters Cg and Cb is also about 3.949 msec. The area of the color filter Crd is so determined that the time for which the color filter Crd is illuminated is about 12.500 msec/ 3 × 7 / (127 + 7) = 0.218 msec. The time for which the color filters Cgd and Cbd is illuminated is also about 0.218 msec.

[0026]

A method of reproducing gray levels about R is described next.

[0027]

The time for which the color filter Cr on the color wheel 202 is illuminated is controlled according to R color image data. Where the first gray level of the R image signal is displayed, the light valve 103 is turned ON for about 0.031 msec of the time for which the color filter Cr is illuminated during one revolution of the color wheel 202. The valve is kept OFF during

the remaining time. Where the second gray level is displayed, the light valve 103 is maintained ON during twice of the ON time for the first gray level, i.e., about 0.062 msec. The valve is kept OFF during the remaining time. Where the third, the fourth, …, and the 127th gray levels are displayed, the light valve is turned ON for 3 times, 4 times, …, 127 times, respectively, the ON time for the first gray level. The light valve is kept OFF during the remaining times. Thus, there are 128 combinations of ON/OFF times including a fully OFF state.

[0028]

A method of increasing the number of gray levels for R to 1024 using the color filter Crd is next described. Where the first gray level by the color filter Crd is displayed, the light valve 103 is kept ON for about 0.031 msec within the time for which the color filter Crd is illuminated during one revolution of the color wheel 202. The valve is kept OFF during the remaining time. Where the second gray level is displayed, the valve is kept ON for twice of the ON time for the first gray level, i.e., 0.062 msec. The valve is kept OFF during the remaining time. Where the third, fourth, …, and 7th gray levels are displayed, the light valve is kept ON for 3 times, 4 times, …, 7 times, respectively, the ON time for the first gray level. The valve is kept OFF during the remaining time.

Thus, 8 gray levels including a fully OFF state can be reproduced.

[0029]

The transmissivity of the color filter Crd is one eighth of that of the color filter Cr. The brightness of the first gray level displayed using only the color filter Crd is one eighth of that of the first gray level displayed using only the color filter Cr. Therefore, 1024 gray levels can be reproduced by displaying the upper-order 7 bits of the color image data quantized with 10 bits by the use of the color filters Cr, Cg, and Cb and displaying the lower-order 3 bits by the use of the color filters Crd, Cgd, and Cbd.

[0030]

With respect to G and B, the upper-order 7 bits are expressed using the color filters Cg and Cb. The lower-order 3 bits are represented using the color filters Cgd and Cbd. In this manner, 1024 gray levels can be reproduced.

[0031]

Subsequently, R, G, and B are projected onto the screen 104 in the same way as in conventional example 1. A color image is created by the human visual sensation characteristics.

[0032]

Where 1024 gray levels are accomplished using the structure described above, the brightness becomes lower than in the first conventional example, thus presenting a problem. The main reason is that the color wheel 202 is divided into 6 segments unlike the first conventional example. Therefore,

there are 6 boundaries between the color filters. The ineffective time is doubled. Consequently, the brightness decreases by about 14%. In addition, the presence of the color filters having a brightness of one eighth lowers the brightness.

[0033]

[Problems to be Solved by the Invention]

In the first conventional display device, the number of gray levels is limited by the minimum switching time in which the light valve 103 is turned ON and OFF. Hence, only 128 gray levels can be reproduced. The second conventional example can increase the number of gray levels to 1024 but a decrease in the brightness occurs.

[0034]

This invention has been made to solve the foregoing problems. It is an object of the present invention to provide a display device which can reproduce gray levels more than the number of gray levels limited by the minimum switching time in which a light valve is turned ON and OFF, the display device suffering from almost no brightness decrease.

[0035]

[Means for Solving the Problems]

A display device in accordance with this invention has a light source and four or more kinds of color filters including a color filter Cw showing almost flat transmission spectral characteristics in the visible range, the display device being

designed to display an image by passing light emitted from said light source through the color filters. The display device is characterized in that information corresponding lower-order *m* bits of a brightness signal of a color image signal quantized with (*n* + *m*) bits (where *n* and *m* are real numbers equal to or greater than 0) is displayed only with the light passed through the color filter Cw, and in that information corresponding to upper-order *n* bits is displayed by light passed through the color filters other than said color filter Cw.

[0036]

The invention also provides a display device having a light source and four or more kinds of color filters including a color filter Cw that transmits white light, the display device being designed to display an image by passing light emitted from said light source through the color filters. The display device is characterized in that information corresponding lower-order *m* bits of a brightness signal of a color image signal quantized with (*n* + *m*) bits (where *n* and *m* are real numbers equal to or greater than 0) is displayed only with the light passed through said color filter Cw, and in that information corresponding to upper-order *n* bits is displayed by light passed through the color filters other than said color filter Cw.

[0037]

In another feature, a display is provided using light transmitted through the color filter Cw only when a signal

corresponding to brightness information of said color image signal is less than a given gray level.

[0038]

[Embodiments of the Invention]

This invention is hereinafter described in detail with reference to the drawings showing its embodiments.

[0039]

Embodiment 1

Fig. 1 is a block diagram showing one example of the structure of a display device in accordance with one embodiment of this invention. Shown in Fig. 1 are a light source 101, a color wheel 2, a light valve 103, a screen 104, a signal converter portion 6, and a driver portion 5.

[0040]

The color wheel 2 is divided into 4 segments including color filters Cr, Cg, and Cb that transmit R, G, and B, respectively. The color wheel 2 further includes a color filter Cw that transmits white light. This filter Cw shows almost flat spectral characteristics, as opposed to the filters Cr, Cg, and Cb in the visible range. Let the color filters Cr, Cg, Cb, and Cw have transmissivities of $fr(\lambda)$, $fg(\lambda)$, $fb(\lambda)$, and $fw(\lambda)$, respectively. $fw(\lambda)$ is so set as to satisfy Equation (1).

[0041]

[Equation 1]

$$\int_{380}^{780} fw(\lambda) \cdot V(\lambda)\, d\lambda = \frac{1}{8} \cdot \int_{380}^{780} \{fr(\lambda) + fg(\lambda) + fb(\lambda)\} \cdot V(\lambda)\, d\lambda \qquad (1)$$

[0042]

where λ is the wavelength of light and $V(\lambda)$ is the relative spectral sensitivity characteristic of the human eye.

It can be seen that the color filter Cw is lower in transmissivity than the color filters Cr, Cg, and Cb, because the right side of equation (1) is multiplied by a coefficient 1/8. In other words, the brightness of the first gray level displayed using only the color filter Cw is one eighth of the brightness achieved when the three color filters Cr, Cg, and Cb are simultaneously set to the first gray level.

[0043]

The display device in accordance with the present embodiment constructed in this way decomposes light into 4 colors by the color filters Cr, Cg, Cb, and Cw. The 4 colors of light are projected via the light valve 103 onto the screen 104, thus reproducing a color image.

[0044]

The operation of the display device of Fig. 1 is next described. Color image data of 10 bits having a frame rate of 60 Hz is input to the signal converter portion 6. This converter portion 6 converts the input color image data as follows and sends it to the driver portion 5. The driver portion 5 also receives a synchronizing signal.

[0045]

The manner in which the signal converter portion 6 converts color image data is now described by referring to Fig. 2, which is a detail block diagram of the signal converter portion 6. In Fig. 2, input terminals 7, 8, and 9 receive 10-bit, color image data Rin, Gin, and Bin, respectively, corresponding to the R, G, and B colors. A brightness signal-calculating unit 10 for calculating brightness data Y satisfies equation (2) below, assuming that the lower-order 3 bits of the input color image data Rin, Gin, and Bin are Sr, Sg, and Sb, respectively. The upper-order 3 bits of the brightness data Y is supplied as a converted color image data Wout to an output terminal 17. Delay-compensating portions 11, 12, and 13 delay with respect to the upper-order 7 bits of the signals Rin, Gin, and Bin coming from the input terminals 7, 8, and 9 by an amount equal to the time taken for the brightness signal-calculating unit 10 to calculate the brightness signal. The obtained data are sent as converted color image data Rout, Gout, and Bout to output terminals 14, 15, and 16, respectively.

[0046]

[Equation 2]

$$Y = 0.299Sr + 0.587Sg + 0.144Sb \qquad (2)$$

[0047]

The output terminals 14, 15, 16, and 17 are connected with the driver portion 5, which in turn creates control signals for

the color wheel 2 and light valve 103 from the converted color image data Rout, Gout, Bout, Wout and from the synchronizing signal and sends the control signals to the color wheel 2 and to the light valve 103.

[0048]

The color wheel 2 makes one revolution in 1/60 msec ≅ 16.667 msec. This rotation is synchronized with the frame rate of the displayed image.

[0049]

The color wheel 2 has 4 kinds of color filters that form only four boundaries. Therefore, the ineffective time is about $15° \times 4 / 360° \times 16.667$ msec = 2.778 msec. The effective time is about 16.667 msec − 2.778 msec = 13.889 msec.

[0050]

The area of the color filter Cr is determined in such a way that light from the light source 101 shines on the color filter Cr of the color wheel 2 for 13.889 msec × 127/(3 × 127 + 7) = 4.546 msec during one revolution of the color wheel 2. The time for which the color filters Cg and Cb are illuminated is also 4.546 msec. The area of the color filter Cw is so set that the time for which the color filter Cw is illuminated is 13.889 msec × 7 (3 × 127 + 7) = 0.251 msec.

[0051]

A method of reproducing gray scales about R is next described.

[0052]

The light valve 103 is controlled according to the converted color image data Rout about R produced from the output terminal 14 of the signal converter portion 6 while the color filter Cr is being illuminated with light. Where the first gray level of the converted color image data Rout about R is displayed, the light valve 103 is kept ON during about 0.036 msec within the time for which the color filter Cr is illuminated during one revolution of the color wheel 2. The valve is kept OFF during the remaining time. Where the second gray level is displayed, the valve is kept ON during twice of the time for the first gray level (i.e., 0.072 msec). The valve is kept OFF during the remaining time. Where the third, fourth, …, and 127th gray levels are displayed, the light valve is kept ON for 3 times, 4 times, …, 127 times, respectively, the ON time for the first gray level. The valve is kept OFF during the remaining time. Thus, there are 128 combinations of ON/OFF times including a fully OFF state.

[0053]

As mentioned above, the human eye does not respond to flickers of 60 Hz or faster and so he or she feels brighter with increasing the ON time within the period of 16.667 msec and feels darker with decreasing the ON time. The human eye perceives the 128 combinations of ON/OFF times as 128 gray levels.

[0054]

In exactly the same way, 128 gray levels are reproduced

about G and B images.

[0055]

A method of reproducing gray levels equal to or more than 129 gray levels using the color filter Cw of the color wheel 2 is described.

[0056]

The upper-order 7 bits of the color image data Rin, Gin, and Bin quantized with 10 bits are displayed using the 128 gray level-reproducing capability of the aforementioned color filters Cr, Cg, and Cb. On the other hand, the lower-order 3 bits of the color image data Rin, Gin, and Bin that are discarded are displayed as converted color image data Wout quantized with 3 bits (i.e., 8 gray levels) using the color filter Cw.

[0057]

Where the first gray level of Wout is displayed, the light valve 103 is kept ON for 0.036 msec within the time for which the color filter Cw is illuminated during one revolution of the color wheel 2. The valve is kept OFF during the remaining time. Where only the second gray level is displayed, the valve is kept ON during twice of the ON time for the first gray level, i.e., 0.072 msec. The valve is kept OFF during the remaining time. Where the third, fourth, …, and seventh gray levels are displayed, the light valve is kept ON during three times, four times, …, and 7 times, respectively, the time for the first gray level. The valve is kept OFF during the remaining time.

In this way, 8 gray levels including a fully OFF state can be reproduced.

[0058]

The transmissivity of the color filter Cw is determined by equation (1). The brightness of the first gray level represented using only the color filter Cw is one eighth of the brightness obtained where the three color filters Cr, Cg, and Cb simultaneously provide their respective first gray levels. Therefore, where the displayed image is a black-and-white image, the upper-order 7 bits of the image data quantized with 10 bits are displayed using the color filters Cr, Cg, and Cb. The lower-order 3 bits are displayed using the color filter Cw. Consequently, 1024 gray levels can be reproduced.

[0059]

This relation is described by referring to Fig. 3. (a) shows an input signal applied to the signal converter portion 6. (b) shows the brightness of an image reproduced by the color filters Cr, Cg, and Cb. (c) shows the brightness of an image reproduced by the color filter Cw. (d) shows the brightness of the resultant of the images shown in (b) and (c) combined by the human visual characteristics. It can be observed from these figures that the number of gray levels shown in (d) is the same as the number of gray levels shown in (a).

[0060]

Where the displayed image is not a black-and-white image

but a color image, the brightness components of the color image data quantized with 10 bits can reproduce 1024 gray levels using the color filters Cr, Cg, Cb, and Cw. However, with respect to color components, only 128 gray levels can be reproduced using the color filters Cr, Cg, and Cb. Furthermore, the chroma deteriorates slightly, because white and black components are mixed by the color filter Cw.

[0061]

However, the visual characteristics of the human eye have such a feature that the eye can discriminate a less number of color gray levels than brightness gray levels. Consequently, this will not present great problems.

Only one color filter Cw is added compared with the first conventional example and so the decrease in the brightness is only about 3%. As a result, the decrease in the brightness presents almost no problems.

[0062]

The color filter Cw is only required to exhibit almost flat spectral transmission characteristics in the visible range. This filter is not limited to a filter that transmits pure white light. For example, the spectral characteristics are allowed to be shifted slightly toward red or blue.

[0063]

Embodiment 2

In Embodiment 1, Cw is used for gray levels ranging from

the first to the 1024th gray level. It is not necessary to use the color filter Cw for all the gray levels. The filter may be employed only for dark image portions. An example of operation in this case is next described by referring to Fig. 4. (a) is a diagram showing an image signal applied to the signal converter portion 6. (b) is a diagram showing the brightness of an image reproduced by the color filters Cr, Cg, and Cb, and is the same as in Embodiment 1. (c) shows the brightness of an image reproduced by the color filter Cw. This filter Cw is used for only the 15th gray level and below. The filter Cw is kept OFF in response to the 16th gray level and above. The resultant brightness of the color filters Cr, Cg, Cb, and Cw is shown in (d).

[0064]

The human eye's capability to discriminate bright portions is lower than the capability to discriminate dark portions. Therefore, where the color filter Cw is used only for dark portions to resolve gray levels, the same advantages can be obtained as Embodiment 1. Furthermore, the 16th and higher gray levels can be displayed in the same way as the prior art display device. The decrease in the chroma due to mixing of white and black components by the color filter Cw can be suppressed to a minimum.

[0065]

Embodiment 3

In Embodiments 1 and 2, 10 bits of image data are separated into the upper-order 7 bits and the lower-order 3 bits and displayed. The present invention is not limited to the bit numbers used herein. For example, $(n + m)$-bit image data (where n and m are any arbitrary real numbers equal to or greater than 0) may be divided into the upper-order n bits and the lower-order m bits and displayed.

[0066]

Embodiment 4

In Embodiments 1-3, Equation (2) is used as a formula for calculating brightness data Y. The invention is not restricted to this calculational formula. Rather, appropriate coefficients may be used according to the spectral characteristics of the color filters Cr, Cg, Cb, and Cw. Furthermore, coefficients may be varied to reduce the size of the hardware. Where signals are transmitted in Y chromatic form as in normal TV, only the Y signal of the sent Y chromatic signal may be used.

[0067]

Embodiment 5

In Embodiments 1-4, a color filter exhibiting flat spectral characteristics in the visible range is used as the color filter Cw. The invention is not limited to this. Rather, the filter may have any desired characteristics as long as it transmits white light within a realizable range. For instance,

the spectral characteristics may have some peaks and valleys, not flat. Filters having these characteristics may have advantages similar to those yielded by the aforementioned ones.

[0068]

[Effects of the Invention]

As described thus far, a display device in accordance with this invention has a light source and four or more kinds of color filters including a color filter Cw showing almost flat transmission spectral characteristics in the visible range, the display device being designed to display an image by passing light emitted from the light source through the color filters. The display device is characterized in that information corresponding lower-order m bits of a color image signal quantized with $(n + m)$ bits is displayed only with the light passed through said color filter Cw, and in that information corresponding to upper-order n bits is displayed by light passed through the color filters other than said color filter Cw. With respect to gray levels that cannot be displayed in the past due to the limitation on the minimum switching time in which a light valve is turned on and off, only brightness information to which human visual sensation is relatively sensitive can be reproduced by the color filter Cw. The gray scale can be reproduced smoothly. In addition, a decrease in the brightness can be suppressed.

[0069]

The invention also provides a display device having a light

source and four or more kinds of color filters including a color filter Cw that transmits white light, the display device being designed to display an image by passing light emitted from said light source through the color filters. The display device is characterized in that information corresponding lower-order m bits of a color image signal quantized with $(n + m)$ bits (where n and m are real numbers equal to or greater than 0) is displayed only with the light passed through said color filter Cw, and in that information corresponding to upper-order n bits is displayed by light passed through the color filters other than said color filter Cw. With respect to gray levels that cannot be displayed in the past due to the limitation on the minimum switching time in which a light valve is turned on and off, only brightness information to which human visual sensation is relatively sensitive can be reproduced by the color filter Cw. The gray scale can be reproduced smoothly. In addition, a decrease in the brightness can be suppressed.

[0070]

In another feature of the invention, a display is provided using light transmitted through the color filter Cw only when a signal corresponding to brightness information of said color image signal is less than a given gray level. Therefore, only dark portions to which human visual sensation is relatively sensitive are reproduced by an increased number of gray levels. Bright portions can be reproduced in the same way as in the past.

A decrease in the chrominance due to mixing of brightness by the color filter Cw can be reduced to a minimum. Consequently, a natural image can be obtained.

[Brief Description of the Drawings]

Fig. 1 is a block diagram showing one example of the structure of a display device in accordance with Embodiment 1 of this invention;

Fig. 2 is a block diagram of a signal converter portion of the display device in accordance with Embodiment 1 of this invention;

Fig. 3 is a diagram illustrating a method of reproducing gray scales used in the display device in accordance with Embodiment 1 of this invention;

Fig. 4 is a diagram illustrating a method of reproducing gray scales used in the display device in accordance with Embodiment 2 of this invention;

Fig. 5 is a block diagram showing one example of the structure of a first conventional example of display device; and

Fig. 6 is a block diagram showing one example of the structure of a second conventional example of display device.

[Legend]

2, 102, 202: color wheels; 5, 105, 205: driver portions;

6: signal converter portion; 7, 8, 9: input terminals;

10: brightness signal-calculating portion;

11, 12, 13: delay-compensating portions;

14, 15, 16, 17: output terminals; 101: light source;

103: light valve; 104: screen

[Name of Document]: Abstract

[Summary]

[Object]

A display device that can eliminate a shortage of the number of gray levels due to a limitation on the minimum switching speed of a light valve and suffers from almost no brightness decrease is obtained.

[Solving Means]

A color filter Cw having nearly flat transmittance characteristics is added to a color wheel 2, other than the three primary colors. Brightness information carried by a color image signal is quantized with ($n + m$) bits. Of this brightness information, information corresponding lower-order m bits is displayed by light passed through the color filter Cw. Information corresponding to higher-order n bits is displayed by light passed through color filters other than the color filter Cw. Consequently, only brightness information to which the human visual sensation is sensitive in terms of gray levels is reproduced by the color filter Cw having a low transmissivity.

[Selected Figure]: Figure 1

Verified Translation Statement

I, Yoshiyuki Sato, hereby declare the following:

I am knowledgeable in Japanese and English. I have reviewed Japanese application no. 079518/1999 and believe the attached document to be an accurate translation thereof.

All statements made herein of my own knowledge are true and all statements made on information and belief are believed to be true. Further, these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: January 29, 2001

Yoshiyuki Sato
Signature of Declarant

09/857,665

#4

DISPLAY DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a display device and, more particularly, to a display device using color filters to reproduce colors.

2. Description of the Prior Art

In recent years, numerous display devices have been available in which color filters are used to decompose light from a light source into N colors that are projected onto a screen for reproducing a color image, where N is a positive integer. Normally, N = 3, and light is decomposed into red (R), green (G), and blue (B) colors which are projected to reproduce a color image. The simplest example of implementation for achieving this is given below.

Fig. 1 shows an example of a display device, comprising a light source 101, a color wheel 102, a light valve 103, a screen 104, and drive electronics 105. The display device shown in Fig. 1 is assumed to project light decomposed into R, G, and B colors, thus reproducing color images.

The operation of the display device constructed as described above is described by referring to Fig. 1. Seven-bit color image data having a frame rate of 60 Hz and a synchronizing signal are applied to the drive electronics 105. The drive electronics 105 create control signals for the color

wheel 102 and for the light valve 103 from the entered color image data and the synchronizing signal. The control signals are fed to the color wheel 102 and to the light valve 103.

The light valve 103 is a device for turning ON or OFF each individual pixel. A digital micromirror device (DMD), a liquid crystal, or the like is used as the light valve 103. Where the DMD is used as the light valve 103, the direction in which light is reflected is controlled for each individual pixel, thus turning ON or OFF the light. Where the light is reflected toward the screen, the device is turned ON. Where the light is reflected toward the outside the screen, the device is turned OFF. This is referred to as control of the reflection.

Where a liquid crystal is used as the light valve 103, the following two types are conceivable. One type controls reflection in the same way as the aforementioned DMD. Another type switches ON and OFF passage of light for each individual pixel. Where the light is transmitted, the device is turned ON. Where the light is not transmitted, the device is turned OFF. The transmitted light is brought to a focus on the screen.

An ultrahigh-pressure mercury lamp is used as the light source 101, for example. Light emitted from this lamp is made to hit a part of the color wheel 102. This color wheel 102 is divided into three segments, for example. These segments are color filters Cr, Cg, and Cb that transmit R, G, and B, respectively. The color wheel 102 makes one revolution in 1/60

msec, i.e., about 16.667 msec (3600 rpm). This rotation is synchronized to the frame rate (60 Hz in the above example) of the displayed image.

Where light from the light source 101 shines on the color filter segment Cr on the color wheel 102, the light valve 103 is controlled by color image data about R. An R image is projected onto the screen 104. With other colors, the light from the light source 101 is similarly projected onto the screen 104 via the color filters on the color wheel 102 and via the light valve 103, and images are displayed.

The times for which the light from the light source 101 is made to shine on the segments of the color wheel 102 during one revolution of the color wheel 102 are next described. The light source 101 illuminates parts of the color wheel 102. The produced light spot has some diameter. Where this light spot is at the boundary between two adjacent color filters, two colors across the boundary will be mixed up. That is, one light spot has two colors of light transmitted through the color filters. This cannot be used for image display. Therefore, where the light spot shines on the boundary, it is necessary to turn OFF the light valve.

For the sake of illustration, it is assumed that the light valve must be kept OFF within an angular range of 15° on the color wheel 102. Of course, this angular range may differ, depending on the size of the light spot and on the sizes of the

segments forming the color filters.

As can be seen from Fig. 1, the boundaries between the color filters on the color wheel 102 are three boundaries between R, G, and B colors. During one revolution of the color wheel 102, it is necessary to turn OFF the light valve 103 for a time corresponding to an angular range of $15 \times 3 = 45°$. This time is referred to as the ineffective time. The other time is referred to as the effective time.

Since the color wheel 102 makes one revolution in about 16.667 msec, the ineffective time is $45°/360° \times 16.667 \cong$ approximately 2.083 msec. Of the effective time, the time for which the light shines on the color filter Cr is equal to the effective time divided by 3, i.e., about 4.862 msec $((1/60 \times (1 - 45°/360°))/3 \cong 16.667 - 2.083)$ msec/three colors. Similarly, the time for which the light shines on the color filters Cg and Cb is about 4.862 msec.

A method of reproducing gray levels is now described by taking the case of R as an example. When the light shines on the color filter Cr during the effective time of the color wheel 102, the light valve 103 is controlled according to an R image signal. Where the first gray level is displayed, the light valve 103 is turned ON for about 0.038 msec within the time for which the light shines on the color filter Cr during one revolution of the color wheel 102. The light valve is kept OFF during the remaining time of about 4.824 msec. Where the second gray level

is displayed, the light valve 103 is turned ON for twice of the ON time for the first gray level, i.e., 0.076 msec. The light valve is kept OFF during the remaining time of 4.786 msec. Where the third, fourth, …, and 127th gray levels are displayed, the light valve is turned ON for 3 times, 4 times, …, and 127 times, respectively, of the ON time for the first gray level. The light valve is kept OFF during the remaining times. Thus, there are 128 combinations of ON/OFF times including a fully OFF state.

The human eye does not respond to flickers higher than 60 Hz, which is generally known as the critical flicker frequency. As the ON time prolongs within the 16.667 msec, the human eye feels brighter. As the ON time shortens, the eye feels darker. The human eye perceives 128 ON/OFF time combinations as 128 gray levels. Light is projected onto the screen such that the light valve is turned ON or OFF for each pixel, and an R image that visually has gray levels is reproduced. With respect to each of G and B, 128 gray levels are reproduced in the same way as in the case of R.

Each image of R, G, and B is projected in turn onto the screen for one third of 1 frame time of about 16.667 msec, i.e., about 5.556 msec. As mentioned above, the human eye does not respond to flickers higher than the critical fusion frequency of 60 Hz and so he or she feels as if three colors were displayed simultaneously. Consequently, a color image is visually reproduced.

In the example given above, gray levels corresponding to 7 bits, i.e., 128 gray levels (2^7 gray levels), are represented. The light valve 103 is switched ON and OFF at intervals of about 0.038 msec, i.e., the time (about 4.862 msec) for which light is made to shine on the color filter Cr divided by 127 (128 - 1) that is the number of gray levels excluding the zeroth gray level at which light is not output.

Where it is attempted to display a wider range of gray scale with the above-described structure, e.g., gray levels (2^8 = 256 gray levels) corresponding to 8 bits, it is necessary to switch ON and OFF the light valve 103 at intervals within the time for which light is made to shine on the color filter Cr divided by 255, i.e., about 0.019 msec, if the principle described above is applied.

Where the light is turned ON and OFF using the light valve 103 such as a DMD as mentioned above, however, the minimum switching time achievable with the presently available DMD is about 0.030 msec. Therefore, it is impossible to switch the device ON and OFF at intervals of about 0.019 msec as described above.

Where the light is turned ON and OFF using the light valve 103 as consisting of a DMD in an attempt to solve the above-described problem, the minimum switching time is about 0.030 msec as described above. A structure capable of displaying 1024 gray levels (2^{10} gray levels) with this structure is

disclosed, for example, in Japanese Unexamined Patent Publication No. 149350/1997.

This disclosed display device is shown in Fig. 2. Note that like components are indicated by like reference numerals in various figures and those components which have been already described in connection with Fig. 1 will not be described below. A color wheel 202 is divided into 6 segments to form color filters Crd, Cgd, and Cbd of lower transmissivity than color filters Cr, Cg, and Cb, in addition to the conventional filters Cr, Cg, and Cb. The transmissivity of the filters Crd, Cgd, and Cbd is one eighth of that of the filters Cr, Cg, and Cb. Thus, gray levels corresponding to the 3 bits, i.e., 2^3 gray levels (8 gray levels), are added.

The structure shown in Fig. 2 and its operation are now described. Drive electronics 205 receive 10-bit color image data having a frame rate of 60 Hz and a synchronizing signal. The drive electronics 205 create control signals for a color wheel 202 and for a light valve 103 from the input color image data and send these control signals to the wheel and to the light valve.

Of the 6 segments on the color wheel 202, the color filters Cr and Crd transmit R. The color filters Cg and Cgd transmit G. The color filters Cb and Cbd transmit B. The transmissivity of the filter Crd is one eighth of that of the filter Cr. The transmissivity of the color filter Cgd is one eighth of that

of the filter Cg. The transmissivity of the color filter Cbd is one eighth of that of the filter Cb.

The color wheel 202 makes one revolution in 1/60 msec ≅ 16.667 msec. This rotation is synchronized to the frame rate of the displayed image. In the structure shown in Fig. 2, there are 6 color filters and so there exist 6 boundaries as can be seen from the figure. In this case, therefore, the ineffective time is about $15° \times 6 / 360° \times 16.667$ msec ≅ 4.167 msec. The effective time is about 16.667 msec − 4.167 msec = 12.500 msec.

The time for which the light from the light source 101 is made to shine on the color filter Cr of the color wheel 202 during one revolution of the color wheel 202 is one third of the aforementioned effective time (12.500 msec) multiplied by a proportion at which light is made to shine on the color filter Cr, i.e., about 12.500 msec / 3 × 127 / (127 + 7) = 3.949 msec. The segment of the color filter Cr is determined based on this time. Similarly, the time for which light is made to hit the color filters Cg and Cb is also about 3.949 msec.

The time assigned to illuminate the color filter Crd is one third of the effective time (12.500 msec) multiplied by the proportion at which the filter Crd is illuminated, i.e., about 12.500 msec/ 3 × 7 / (127 + 7) = 0.218 msec. The segment of the color filter Crd is determined based on this time. Similarly, the time for which the color filters Cgd and Cbd are illuminated is about 0.218 msec.

A method of reproducing gray levels is now described, taking R as an example. The time for which the color filter Cr of the color wheel 202 is illuminated is controlled according to R color image data. Where the first gray scale of the R image signal represented by the filter Cr is displayed, the light valve 103 is turned ON for about 0.031 msec (= 3.949 msec/127) of the time for which the filter Cr is illuminated during one revolution of the color wheel 202. The valve 103 is kept OFF during the remaining time.

Where the second gray level represented by the color filter Cr is displayed, the light valve 103 is maintained ON during twice of the ON time for the first gray level represented by the filter Cr, i.e., about 0.062 msec. The valve is kept OFF during the remaining time. Where the third, the fourth, …, and the 127th gray levels are displayed, the light valve is turned ON for 3 times, 4 times, …, 127 times, respectively, of the ON time for the first gray level. The light valve is kept OFF during the remaining times. Thus, there are 128 combinations of ON/OFF times and thus 128 gray levels can be represented.

A method of displaying 1024 R gray levels using the color filter Crd is now described. Where the first gray level represented by the filter Crd is displayed, the light valve 103 is kept ON for about 0.031 msec (= 0.218 msec/7) within the time for which the filter Crd is illuminated during one revolution of the color wheel 202. The valve is kept OFF during the remaining

time. Where the second gray level represented by the filter Crd is displayed, the valve is kept ON for twice of the ON time for the first gray level represented by the filter Crd, i.e., 0.062 msec. The valve is kept OFF during the remaining time. Where the third, fourth, …, and 7th gray levels represented by the filter Crd are displayed, the light valve is kept ON for 3 times, 4 times, …, 7 times, respectively, of the ON time for the first gray level represented by the filter Crd. The light valve is kept OFF during the remaining time. Thus, there are 8 combinations of ON/OFF times including a fully OFF state and thus 8 gray levels can be represented.

The transmissivity of the color filter Crd is one eighth of that of the filter Cr. The brightness of the first gray level displayed using only the color filter Crd is one eighth of that of the first gray level displayed using only the filter Cr. That is, using combinations of the color filters Cr and Crd, 128 gray levels (provided by the color filter Cr) x 8 gray levels (provided by the color filter Crd) = 1024 gray levels (2^{10} gray levels) can be represented.

Accordingly, of color image data (R image data in this example) quantized with 10 bits (2^{10}), the upper-order 7 bits are expressed using the color filter Cr, while the lower-order 3 bits are expressed using the color filter Crd. In this way, 1024 gray levels can be reproduced.

With respect to G and B, the upper-order 7 bits are

expressed using the color filters Cg and Cb. The lower-order 3 bits are represented using the color filters Cgd and Cbd. In this manner, 1024 gray levels can be reproduced. Images of R, G, and B are projected onto the screen 104 by this gray scale control. A color image is perceived by the human visual characteristics.

Where 1024 gray levels are expressed using the structure and procedure described above, the light-transmitting region of the color wheel 202 is divided into 6 segments corresponding to the different colors and different gray levels. Therefore, there are 6 boundaries between the color filters. The ineffective time due to the boundaries is doubled compared with the case in which there are only three boundaries between color filters. Finally, the brightness of the image projected onto the screen is decreased by about 14%.

In addition to this decrease in the brightness, the presence of the color filters Crd, Cgd, and Cbd having a transmissivity that is only one eighth of that of the color filters Cr, Cg, and Cb lowers the brightness.

SUMMARY OF THE INVENTION

In view of the foregoing problems, the present invention has been made.

It is an object of the present invention to provide a display device which is capable of representing gray levels more

than the number of gray levels limited by the minimum switching time at which a light valve is turned ON and OFF and which suffers almost no brightness decrease.

A display device in accordance with the present invention acts to display an image according to input image data and comprises a light source, light-transmitting filters for separating the light from the light source into at least four kinds of light including white light, and a light valve for projecting each kind of light transmitted through the filters onto a screen.

Some gray levels have been heretofore impossible to display due to restrictions imposed by the minimum switching time at which the light valve is turned ON and OFF. Information about only visually sensitive brightness levels is reproduced using the light-transmitting filter corresponding to white light. Hence, smoother gray-scale representation can be accomplished without deteriorating the brightness.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of the prior art display device;

Fig. 2 is a block diagram of a known display device disclosed in Japanese Unexamined Patent Publication No. 149350/1997;

Fig. 3 is a block diagram of a display device in accordance with the present invention;

Fig. 4 is a block diagram of a signal converter portion in a display device in accordance with the invention;

Fig. 5 is a graph illustrating a method of displaying gray levels with a display device in accordance with the invention; and

Fig. 6 is a graph illustrating another method of displaying gray levels with a display device in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

First Embodiment

Referring to Fig. 3, there is shown a block diagram of a display device in accordance with the present invention. This display device comprises a light source 101, a color wheel 2, a light valve 103, a screen 104, a signal converter portion 6, and drive electronics 5.

As shown in Fig. 3, the color wheel 2 is divided into 4 segments including color filters Cr, Cg, and Cb that transmit R, G, and B, respectively. The color wheel 2 further includes a color filter Cw such as a neutral density filter that transmits white light. This filter Cw shows almost flat spectral characteristics, as opposed to the filters Cr, Cg, and Cb. Let the color filters Cr, Cg, Cb, and Cw have transmissivities of $fr(\lambda)$, $fg(\lambda)$, $fb(\lambda)$, and $fw(\lambda)$, respectively. $fw(\lambda)$ is so set as to satisfy Eq. (1) below.

(1)

where (λ) is the wavelength of light, $V(\lambda)$ is the relative spectral sensitivity characteristic of the human eye, and $1/K$ is a coefficient determining the transmissivity of Cw.

If the coefficient K at the right side of Eq. (1) above is set to 8 ($K = 8$), the color filters Cw, Cr, Cg, and Cb assume such transmissivities that the brightness of the first gray level represented using only the color filter Cw is one eighth of the brightness achieved when the three filters Cr, Cg, and Cb simultaneously represent their first gray levels. That is, the integrated value of the transmissivity in the visible range (light wavelength λ lies between 380 nm and 780 nm) of the light-transmitting filter (color filter Cw) corresponding to white light is smaller than the integrated values of the transmissivities in the visible range of the other light-transmitting filters Cr, Cg, and Cb.

As mentioned above, where a light valve such as a DMD is used, if the minimum switching time is 0.030 nm, it is difficult to achieve 256 gray levels. Therefore, $1/K$ is set to $1/2^P$ (where P is a natural number), i.e., 1/2, 1/4, 1/8, 1/16, and so forth. However, where K has a small value, the minimum switching time of the light valve poses a constraint. Where K has a large value, the segment Cw widens and thus the color filters Cr, Cg, and Cb become narrowed. This will narrow the full range of gray scale in representing R, G, and B colors. Of these limiting conditions,

$K = 8$ is selected because it is well applied to a display device. This case is discussed below.

The display device in accordance with the present embodiment constructed in this way decomposes light into 4 colors by the color filters Cr, Cg, Cb, and Cw. The 4 colors of light are projected via the light valve 103 onto the screen 104, thus reproducing a color image.

The operation of the display device shown in Fig. 3 is next described. Color image data of 10 bits having a frame rate of 60 Hz is input to the signal converter portion 6. This converter portion 6 converts the input color image data as follows and sends it to the drive electronics 5. The drive electronics 5 also receive a synchronizing signal.

The manner in which the signal converter portion 6 converts its input color image data is now described by referring to Fig. 4, which is a detail block diagram of the signal converter portion 6. This converter portion 6 has input terminals 7, 8, and 9 receiving 10-bit, color image data Rin, Gin, and Bin, respectively, corresponding to the R, G, and B colors.

The signal converter portion 6 further includes a brightness signal calculating unit 10 for calculating brightness data Y satisfying Eq. (2) below, assuming that the lower-order 3 bits of the input color image data Rin, Gin, and Bin are Sr, Sg, and Sb, respectively. The upper-order 3 bits of the brightness data Y is supplied as a converted color image

data Wout to an output terminal 17. Delay compensating portions 11, 12, and 13 delay the upper-order 7 bits of the signals Rin, Gin, and Bin coming from the input terminals 7, 8, and 9 by an amount equal to the time taken for the signal calculating unit 10 to calculate the brightness signal. The obtained data are sent as converted image data Rout, Gout, and Bout to output terminals 14, 15, and 16, at the timing of the data Wout.

$$Y = 0.299Sr + 0.587Sg + 0.114Sb \tag{2}$$

The output terminals 14, 15, 16, and 17 are connected with the drive electronics 5, which in turn create control signals for the color wheel 2 and light valve 103 from the converted color image data Rout, Gout, Bout,Wout and from the synchronizing signal and send the control signals to the color wheel 2 and to the light valve 103.

The color wheel 2 makes one revolution in 1/60 msec ≅ 16.667 msec (3600 rpm). This rotation is synchronized with the frame rate of the displayed image. The color wheel 2 has 4 color filters that form four boundaries as can be seen from the figure. In this case, therefore, the ineffective time is about 15° × 4 / 360° × 16.667 msec ≅ 2.778 msec. The effective time is about 16.667 msec - 2.778 msec = 13.889 msec.

During one revolution of the color wheel 2, the time assigned to illuminate the color filter Cr of the color wheel 2 with the light from the light source 101 is 4.546 msec, for the following reason. The three segments Cr, Cg, and Cb produce

128 gray levels. One segment Cw produces 8 gray levels. The effective time of about 13.889 msec corresponds to these three segments Cr, Cg, Cb and one segment Cw. Since the color filter Cr produces 128 gray levels, the ratio of the time assigned to the color filter Cr to the effective time of about 13.889 msec is found by calculating (the time for which the color filter Cr is illuminated) divided by (the time for which the color filter Cr is illuminated × the time for the 3 segments + the time for which the color filter Cw is illuminated). That is , the time assigned to the color filter Cr is about 13.889 msec × 127/(3×127+7)=4.546 msec. The segment Cr is determined based on this time of 4.546 msec. Similarly, the color filters Cg and Cb are illuminated for 4.546 msec.

The time assigned to illuminate the color filter Cw is discussed. The effective time of about 13.889 msec corresponds to 3 segments Cr, Cg, and Cb producing 128 gray levels and 1 segment Cw producing 8 gray levels. Since the segment of the color filter Cw produces 8 gray levels, the ratio of the time assigned to the color filter Cw to the effective time is found by calculating (the time for which the color filter Cw is illuminated) divided by (the time for which the color filter Cr is illuminated × the time for the 3 segments + the time for which the color filter Cw is illuminated). That is, about 13.889 msec × 7 / (3 × 127 + 7) = 0.251 msec is the time assigned to the color filter Cw. The segment of the color filter Cw is

determined based on this time.

A method of reproducing gray scales of R is now described. The light valve 103 is controlled according to the converted color image data Rout about R produced from the output terminal 14 of the signal converter portion 6 while the color filter Cr is being illuminated. Where the first gray level of the converted color image data Rout about R is displayed, the light valve 103 is kept ON during about 0.036 msec (4.546 msec/177 gray levels) within the time for which the color filter Cr is illuminated during one revolution of the color wheel 2. The valve 103 is kept OFF during the remaining time. Where the second gray level is displayed, the valve 103 is kept ON during twice of the time for the first gray level (i.e., 0.072 msec). The valve 103 is kept OFF during the remaining time. Where the third, fourth, …, and 127th gray levels are displayed using the Rout, the light valve 103 is kept ON for 3 times, 4 times, …, 127 times, respectively, of the ON time for the first gray level of the Rout. The valve 103 is kept OFF during the remaining time. Thus, there are 128 combinations of ON/OFF times including a fully OFF state.

As mentioned above, the human eye does not respond to flickers higher than the critical fusion frequency of 60 Hz and so he or she feels brighter with increasing the ON time within the period of 16.667 msec and feels darker with decreasing the ON time. The human eye perceives the 128 combinations of ON/OFF

times as 128 gray levels. In exactly the same way, 128 gray levels are reproduced from G and B.

Now, a method of reproducing gray scales of 129 and more using the color filter Cw is described. Of the color image data Rin, Gin, and Bin quantized with 10 bits, the upper-order 7 bits are displayed using the capability of the color filters Cr, Cg, and Cb to reproduce 128 gray levels. Of the color image data Rin, Gin, and Bin quantized with 10 bits, the lower-order 3 bits are displayed as 3-bit color image data Wout (having 2^3 gray levels = 8 gray levels) using the color filter Cw.

Where the first gray level of the 3-bit color image data Wout is displayed, the light valve 103 is kept ON for 0.036 msec (= 0.251 msec/7) within the time for which the color filter Cw is illuminated during one revolution of the color wheel 2. The valve 103 is kept OFF during the remaining time. Where the second gray level of Wout is displayed, the valve 103 is kept ON during twice of the ON time for the first gray level, i.e., 0.072 msec. The valve 103 is kept OFF during the remaining time. Where the third, fourth, …, and seventh gray levels are displayed, the light valve 103 is kept ON during three times, four times, …, and 7 times, respectively, of the time for the first gray level represented by Wout. The valve 103 is kept OFF during the remaining time. In this way, 8 gray levels including a fully OFF state can be represented.

With respect to the transmissivity of the color filter

Cw, it is now assumed that $K = 8$, which is substituted into Eq. (1). In this case, the brightness of the first gray level of Wout represented using only the color filter Cw is one eighth of the brightness obtained where the three color filters Cr, Cg, and Cb simultaneously provide their respective first gray levels. Therefore, where the display image is a black-and-white image, the upper-order 7 bits of the image data quantized with 10 bits can represent 2^7 gray levels = 128 gray levels using the color filters Cr, Cg, and Cb. The lower-order 3 bits can represent 2^3 gray levels = 8 gray levels using the color filter Cw. Consequently, 1024 gray levels can be represented.

This is described in detail by referring to Figs. 5(a)-5(d). Fig. 5(a) shows a signal applied to the signal converter portion 6. Fig. 5(b) shows the brightness of an image reproduced by the color filters Cr, Cg, and Cb. Fig. 5(c) shows the brightness of an image reproduced by the color filter Cw. Fig. 5(d) shows the brightness of the resultant of the images shown in Figs. 5(b) and 5(c) perceived by the human visual characteristics. It can be observed that the number of gray levels shown in Fig. 5(d) is the same as the number of gray levels shown in Fig. 5(a).

Where the displayed image is not a black-and-white image but a color image, the brightness components of the color image data quantized with 10 bits can produce 1024 gray levels using the color filters Cr, Cg, Cb, and Cw. However, with respect to

color components, only 128 gray levels can be produced using the color filters Cr, Cg, and Cb. Furthermore, the chroma deteriorates slightly, because white and black components are mixed by the color filter Cw. However, the visual characteristics of the human eye have such a feature that the eye can discriminate a less number of color gray levels than brightness gray levels. Consequently, this will not present great problems in practical situations.

The addition of only the color filter Cw to the three color filters Cr, Cg, and Cb described above can increase the number of gray levels of brightness. Therefore, the decrease in the brightness is only about 3%, compared with the instrument comprising the three color filters. As a result, the effects of the decrease in the brightness present almost no problems.

The color filter Cw is only required to exhibit almost flat spectral transmission characteristics in the visible range. This filter is not limited to a filter that transmits pure white light. For example, to adjust the color temperature of the reproduced image, the spectral characteristics are allowed to be shifted slightly toward red or blue.

Second Embodiment

In the first embodiment, the color filter Cw is used from the first to the 1024th gray level. It is not necessary to use the color filter Cw for all the gray levels. The filter Cw may

be employed only for dark image portions. An example of operation in this case is next described by referring to Figs. 6(a)-6(d). Fig. 6(a) shows an image signal applied to the signal converter portion 6. Fig. 6(b) shows the brightness of an image reproduced by the color filters Cr, Cg, and Cb, and is the same as obtained in the first embodiment. Fig. 6(c) shows the brightness of an image reproduced by the color filter Cw. This filter Cw is used for only the 15th gray level and below. The filter Cw is kept OFF in response to the 16th gray level and above. The resultant brightness of the color filters Cr, Cg, Cb, and Cw is shown in Fig. 6(d).

The human eye's capability to discriminate bright portions is lower than the human eye's capability to discriminate dark portions. Therefore, where the color filter Cw is used only for dark portions to resolve gray levels, the same advantages can be obtained as the first embodiment. Furthermore, the 16th and higher gray levels can be displayed in the same way as the prior art instrument. The decrease in the chroma due to mixing of white and black components by the color filter Cw can be suppressed to a minimum.

<u>Third Embodiment</u>

In the first and second embodiments, 10 bits of image data are separated into the upper-order 7 bits and the lower-order 3 bits and displayed. The present invention is not limited to this separation method. For example, (n + m)-bit image data

(where n and m are any arbitrary numbers equal to or greater than 0) may be divided into the upper-order n bits and the lower-order m bits and displayed. It is only necessary that the upper-order n bits and the lower-order m bits suitable for the characteristics of the display device be established.

Fourth Embodiment

In the first through third embodiments, Eq. (2) is used to calculate brightness data Y. The invention is not restricted to the use of this equation. Rather, appropriate coefficients may be used according to the spectral characteristics of the color filters Cr, Cg, Cb, and Cw. Furthermore, coefficients assigned to the filters Sr, Sg, and Sb may be appropriately varied to reduce the size of the hardware.

Where signals are transmitted such that a Y signal (luminance signal) and a chrominance signal are combined as in normal TV, only the Y signal may be used, though the chrominance signal is also transmitted.

Fifth Embodiment

In the first through fourth embodiments, a color filter exhibiting flat spectral characteristics in the visible range is used as the color filter Cw. The invention is not limited to the use of this filter. Rather, the filter may have any desired characteristics as long as it transmits white light within a realizable range. For instance, the characteristic curve may

have some peaks and valleys. Filters having these characteristics may have advantages similar to those yielded by the aforementioned filters.

In the descriptions provided thus far, color filters corresponding to Y (yellow), M (magenta), and C (cyan) may be formed on the color wheel, in addition to R, G, and B. The color filters are not always restricted to R, G, and B color filters.

The invention may be embodied in other specific forms without departing from the spirit or essential parts thereof. The above embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

WHAT IS CLAIMED IS:

1. A display device for displaying an image according to input image data that is digital data, said display device comprising:

a light source for producing light;

light-transmitting filters for separating the light from said light source into at least four kinds of light including white light, said light-transmitting filters including a white-transmitting filter for transmitting white light and non-white transmitting filters;

a light valve for projecting each kind of light from said light-transmitting filters onto a screen;

said white light-transmitting filter being used to display information corresponding to lower-order bits of said digital data; and

said non-white light-transmitting filters being used to display information corresponding to higher-order bits of said digital data.

2. The display device of claim 1, wherein said white light-transmitting filter has spectral characteristics that are almost flat in the visible range of wavelengths of the light.

3. The display device of claim 1, wherein if a brightness required by the input image data is lower than a given gray level, information is displayed using said white light-transmitting filter or said non-white light-transmitting

filters, and if said brightness is higher than said given gray level, information is displayed using only said non-white light-transmitting filters.

4. The display device of claim 1, wherein said light valve is of the reflective type.

5. The display device of claim 1, wherein said light valve is of the transmissive type.

6. The display device of claim 1, wherein a value obtained by integrating the product of spectral transmission factor of said white light-transmitting filter in the visible range and spectral luminous efficiency with respect to wavelength is less than sum of values obtained by integrating the product of spectral transmission factor of each of said non-white light-transmitting filters in the visible range and spectral luminous efficiency with respect to wavelength.

7. The display device of claim 1, wherein brightness created by a first gray level represented via said white light-transmitting filter is lower than brightness created by a first gray level represented via said non-white light-transmitting filters.

ABSTRACT OF THE DISCLOSURE

There is disclosed a display device using a color wheel having a color filter Cw, in addition to normal color filters corresponding to the three primary colors. The filter Cw has almost flat spectral transmission characteristics. Brightness information included in a color image signal is quantized with (n + m) bits. Information corresponding to the lower-order n bits is displayed by light transmitted through the filter Cw. Information corresponding to the upper-order n bits is displayed by light transmitted through the normal color filters. Only brightness information to which the human eye is visually sensitive is reproduced by the filter Cw having a lower transmissivity. This can eliminate a lack of the number of gray levels due to a constraint on the minimum switching speed of a light valve. Furthermore, the brightness little deteriorates.

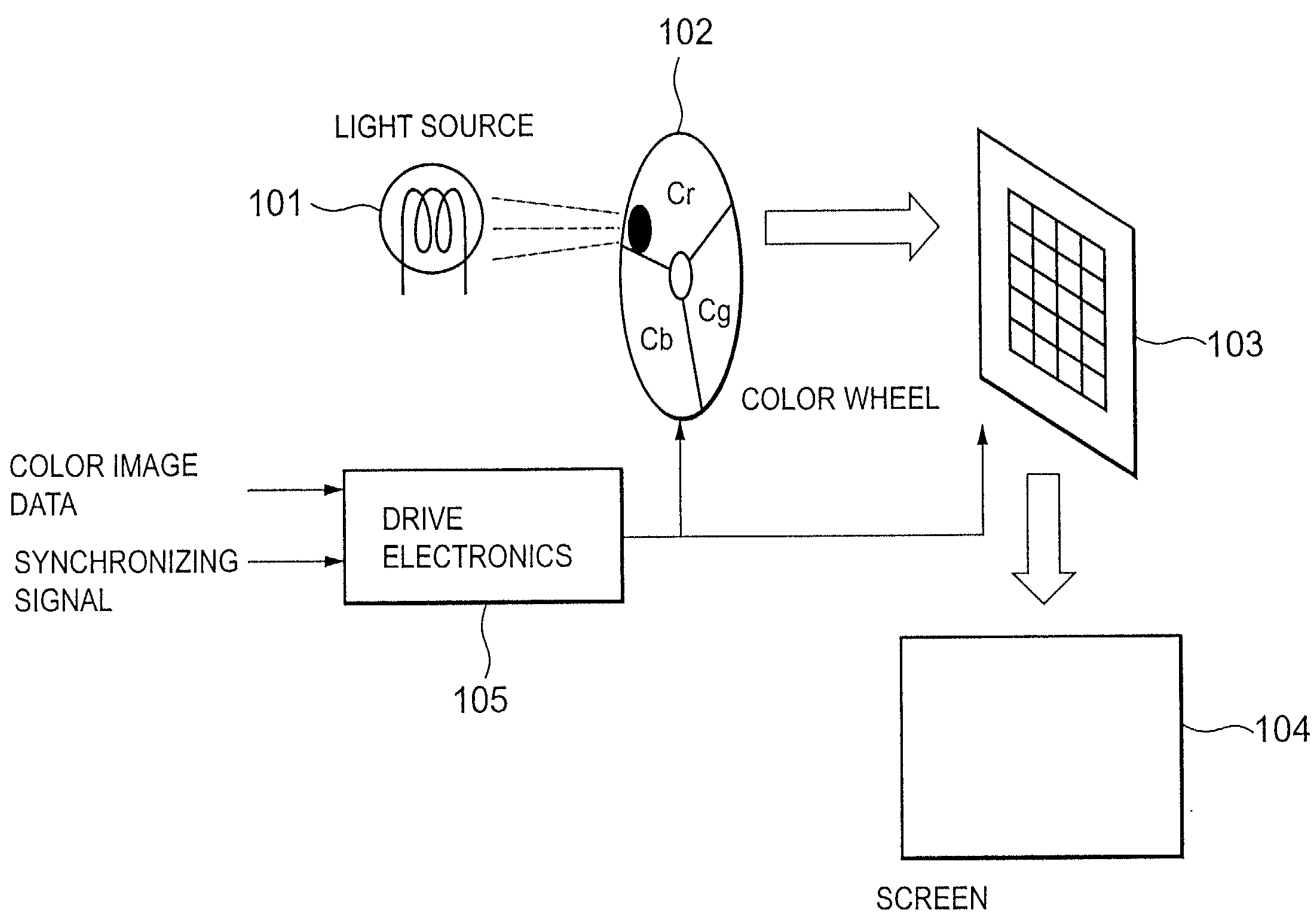


Fig.1 PRIOR ART

Fig.2 PRIOR ART

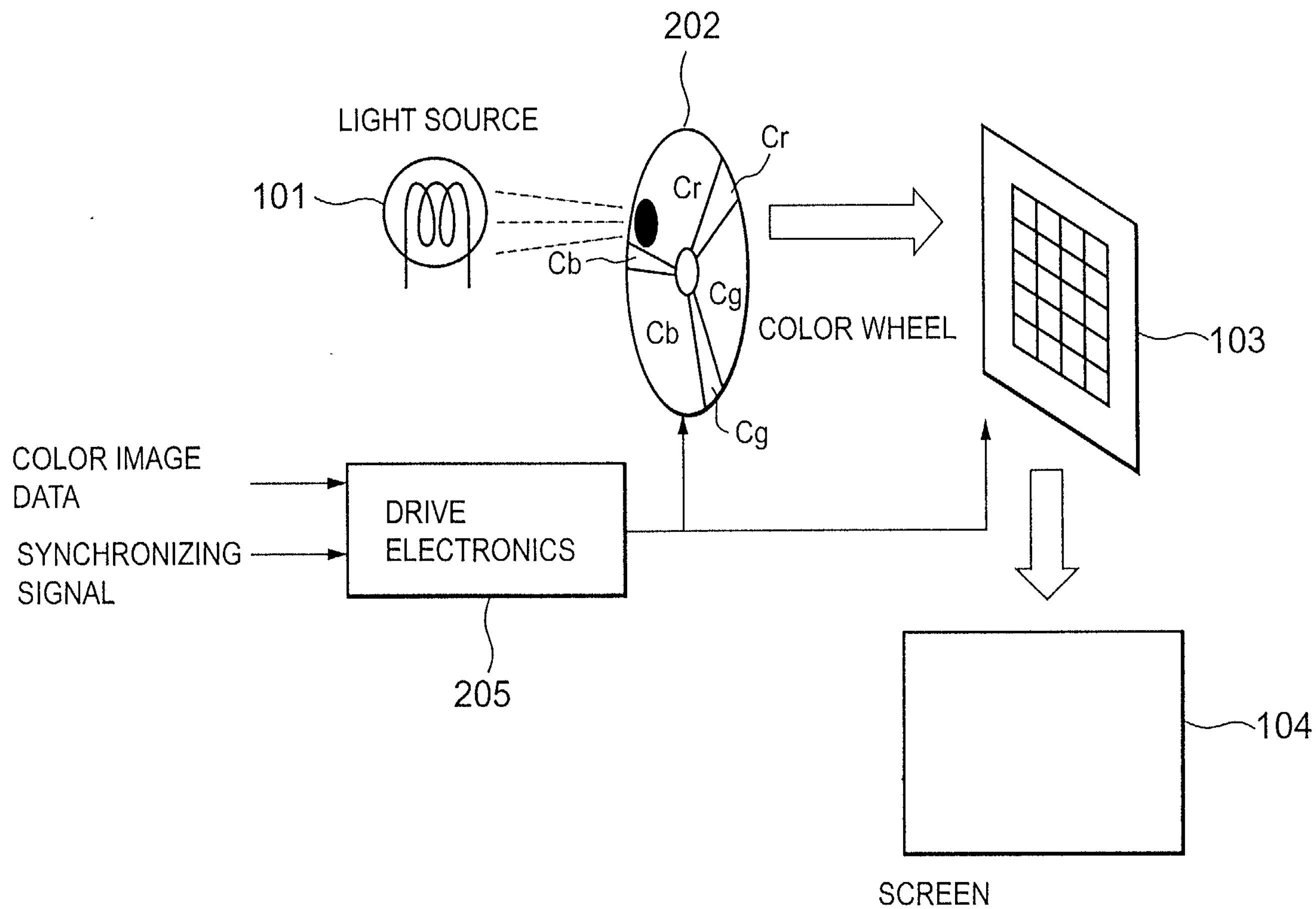


Fig.3 PRIOR ART

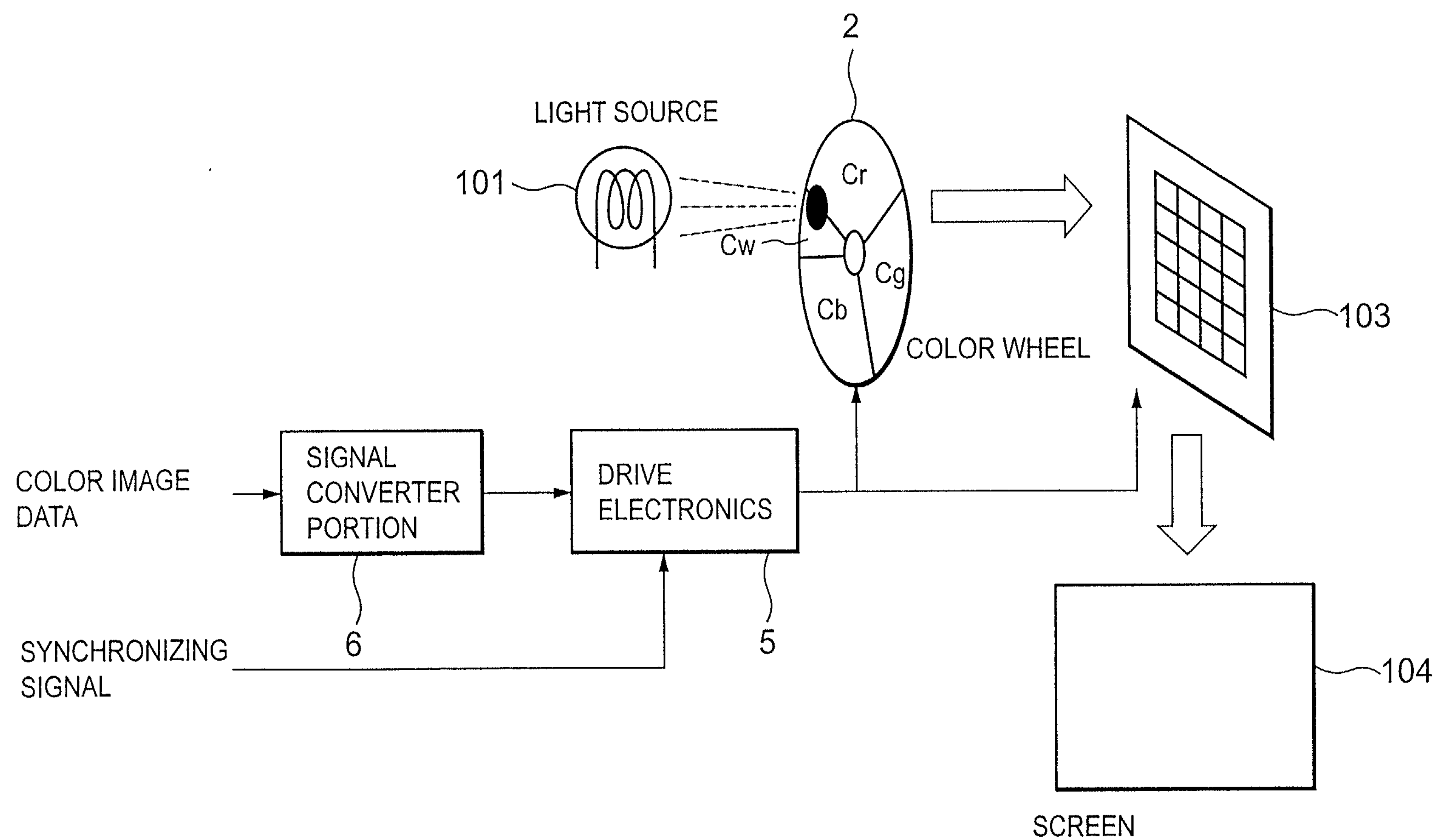


Fig.4

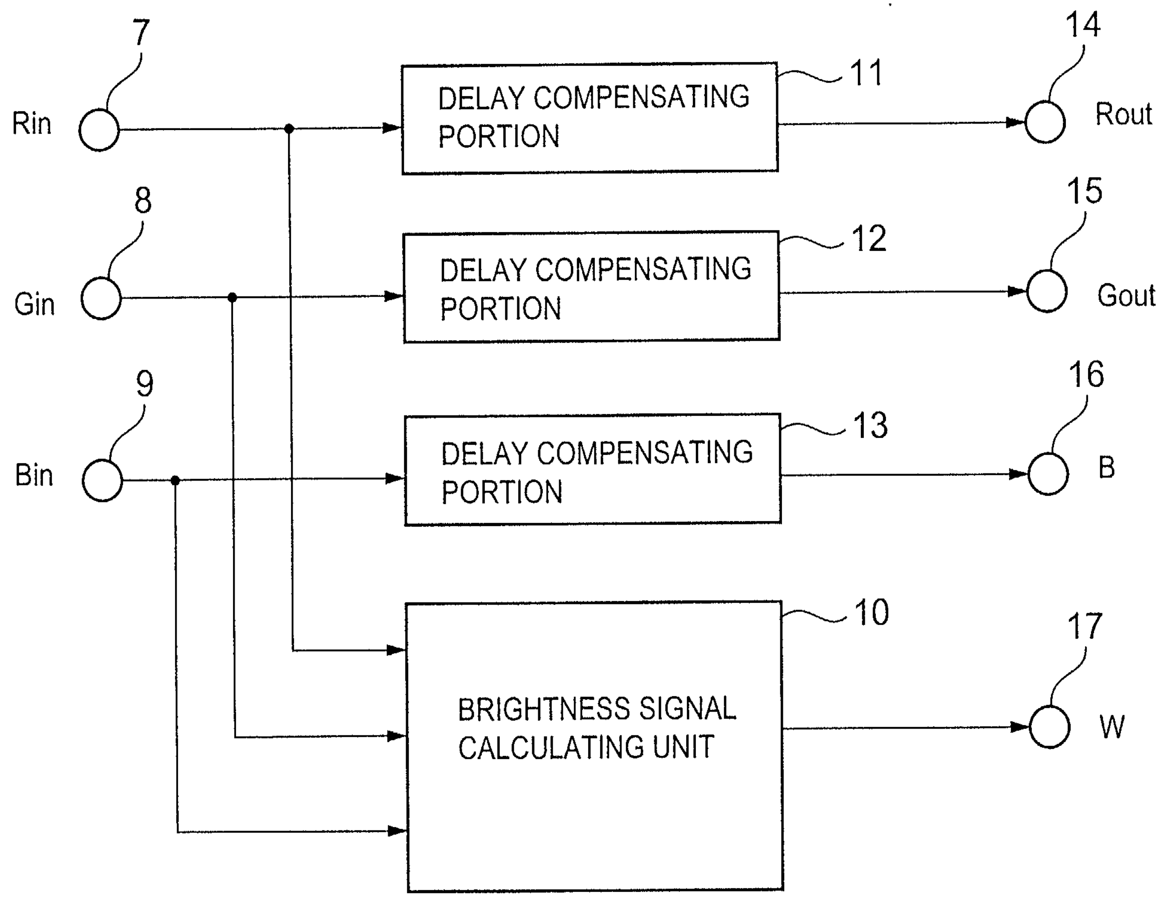

7
Rin
8
Gin
9
Bin
DELAY COMPENSATING PORTION
11
DELAY COMPENSATING PORTION
12
DELAY COMPENSATING PORTION
13
BRIGHTNESS SIGNAL CALCULATING UNIT
10
14
Rout
15
Gout
16
B
17
W

Fig.5(a)

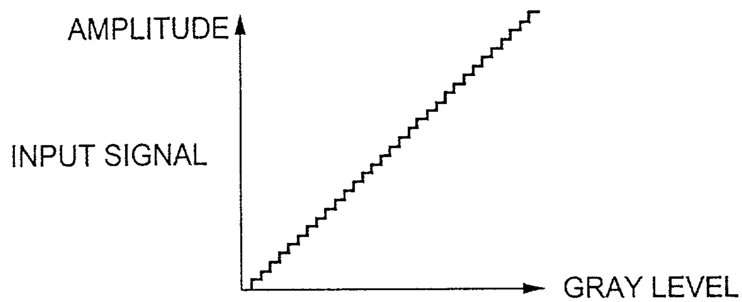


Fig.5(b)

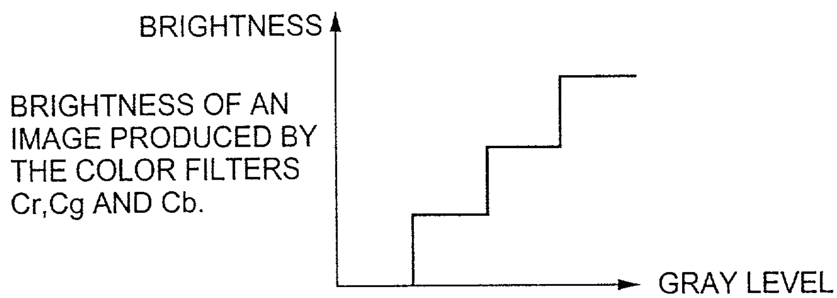


Fig.5(c)

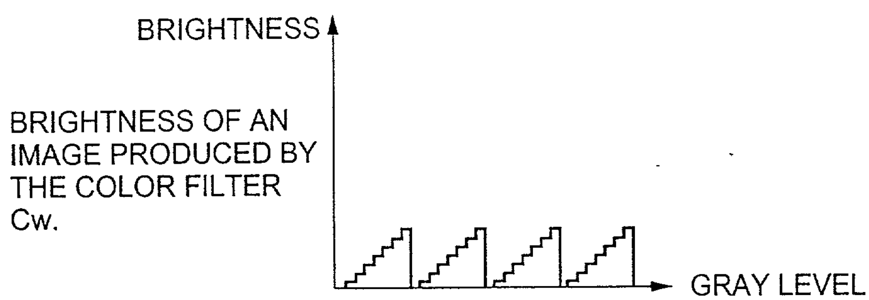


Fig.5(d)

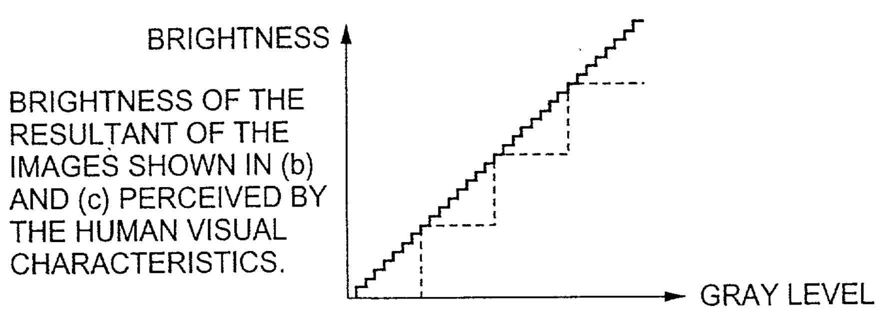


Fig.6(a)

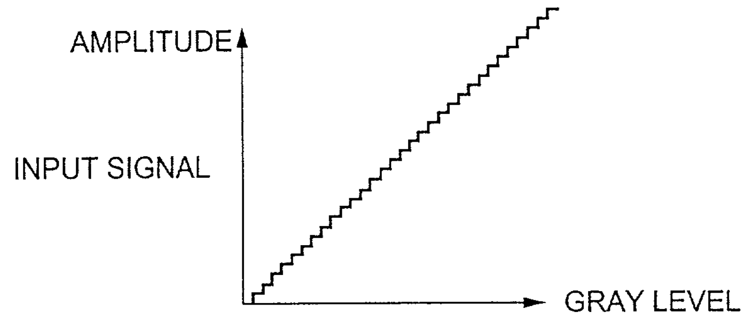


Fig.6(b)

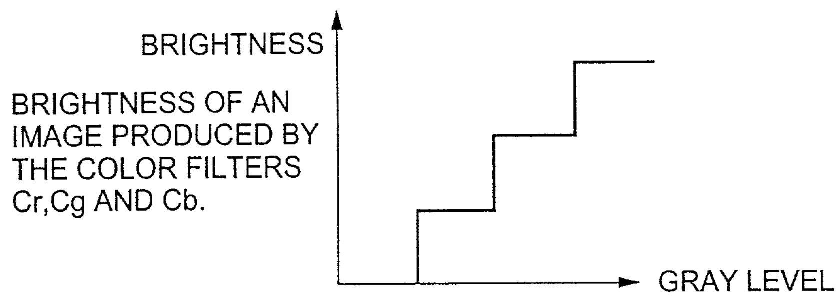


Fig.6(c)

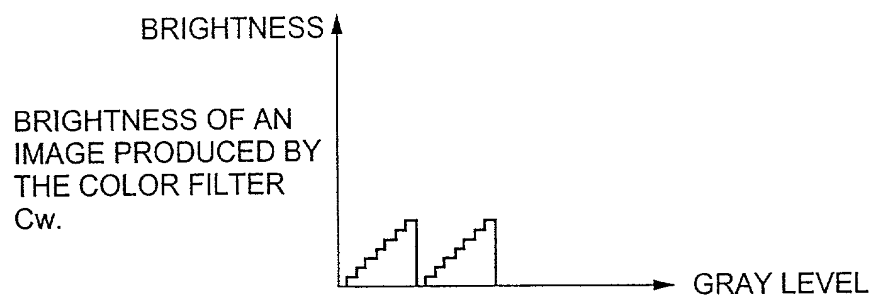
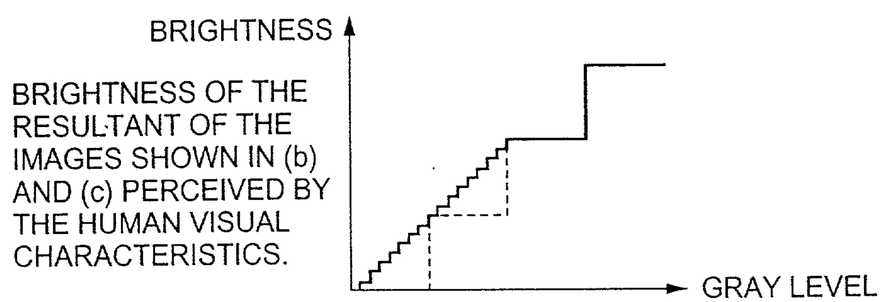


Fig.6(d)



Attorney Docket No. 0925-0154P

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COMBINED DECLARATION AND POWER OF ATTORNEY FOR PATENT AND DESIGN APPLICATIONS

As a below named inventor, I hereby declare that: my residence, post office address and citizenship are as stated next to my name; that I verily believe that I am the original, first and sole inventor (if only one inventor is named below) or an original, first and joint inventor (if plural inventors are named below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

Insert Title: DISPLAY DEVICE

Fill in Appropriate Information - For Use Without Specification Attached:

the specification of which is attached hereto. If not attached hereto,
the specification was filed on January 12, 2000 as
United States Application Number 09/481,391 ;
and amended on ______ (if applicable) and/or
the specification was filed on ______ as PCT
International Application Number ______ ; and was
amended under PCT Article 19 on ______ (if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

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Insert Priority Information: (if appropriate)

Prior Foreign Application(s)

(Number)	(Country)	(Month/Day/Year Filed)	Priority Claimed Yes	Priority Claimed No
079518/1999	Japan	March 24, 1999	☒	☐
			☐	☐
			☐	☐
			☐	☐

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(Application Number)	(Filing Date)

All Foreign Applications, if any, for any Patent or Inventor's Certificate Filed More than 12 Months (6 Months for Designs) Prior to the Filing Date of This Application:

Insert Requested Information: (if appropriate)

Country	Application Number	Date of Filing (Month/Day/Year)

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Insert Prior U.S. Application(s): (if any)

(Application Number)	(Filing Date)	(Status - patented, pending, abandoned)

I hereby appoint the following attorneys to prosecute this application and/or an international application based on this application and to transact all business in the Patent and Trademark Office connected therewith and in connection with the resulting patent based on instructions received from the entity who first sent the application papers to the attorneys identified below, unless the inventor(s) or assignee provides said attorneys with a written notice to the contrary:

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Insert Residence; Insert Citizenship →
Insert Post Office Address →

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*DATE OF SIGNATURE

BIRCH, STEWART, KOLASCH & BIRCH, LLP

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ASSIGNMENT

Application No. 09/481,391 Filed January 12, 2000

Insert Name(s) of Inventor(s)

WHEREAS, Koji MINAMI
Yoshiteru SUZUKI
Kohei TERAMOTO
Hiroaki SUGIURA
Shinsuke SHIKAMA

(hereinafter designated as the undersigned) has (have) invented certain new and useful improvements in

Insert Title of Invention

DISPLAY DEVICE

for which an application for Letters Patent of the United States of America has been executed by the undersigned (except in the case of a provisional application).

Insert Date of Signing of Application

on ____________________; and

Insert Name of Assignee

WHEREAS, Mitsubishi Denki Kabushiki Kaisha

Insert Address of Assignee

of 2-3, Marunouchi 2-Chome, Chiyoda-ku, TOKYO 100-8310 JAPAN

its heirs, successors, legal representatives and assigns (hereinafter designated as the Assignee) is desirous of acquiring the entire right, title and interest in and to said invention and in and to any Letters Patent(s) that may be granted therefor in the United States of America and

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☐ in any foreign countries.

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The undersigned agree(s) to execute all papers necessary in connection with this application and any continuing, divisional, conversion or reissue applications thereof and also to execute separate assignments in connection with such applications as the Assignee may deem necessary or expedient.

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In witness whereof, executed by the undersigned on the date(s) opposite the undersigned name(s).

Date Mar. 7. 2001, Name of Inventor Koji Minami
(signature) Koji MINAMI

Date Mar. 7, 2001, Name of Inventor Yoshiteru Suzuki
(signature) Yoshiteru SUZUKI

Date Mar. 8, 2001, Name of Inventor Kohei Teramoto
(signature) Kohei TERAMOTO

Date Mar. 8, 2001, Name of Inventor Hiroaki Sugiura
(signature) Hiroaki SUGIURA

Date Mar. 7, 2001, Name of Inventor Shinsuke Shikama.
(signature) Shinsuke SHIKAMA

Date ______, Name of Inventor ______
(signature)

October 1998